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(54) **Thermal control system for multiple print bar system.**

(57) The temperatures of LED print bars (40,50,60) utilized in a printing system are maintained within a specified differential range, with respect to each other. Each print bar has an associated heating (40A,50A,60A) and cooling (40C,50C,60C) element. The temperature of each print bar is monitored and compared during operation. When a temperature differential greater than a preset tolerance range is detected, either the hotter operating print bar is cooled or the lower operating print bar is heated, or a combination of cooling and heating is applied to the out-of-tolerance print bars. The cooling and/or heating of the print bars is continued until the temperature differential is reduced so as to be within the preselected or predefined range.

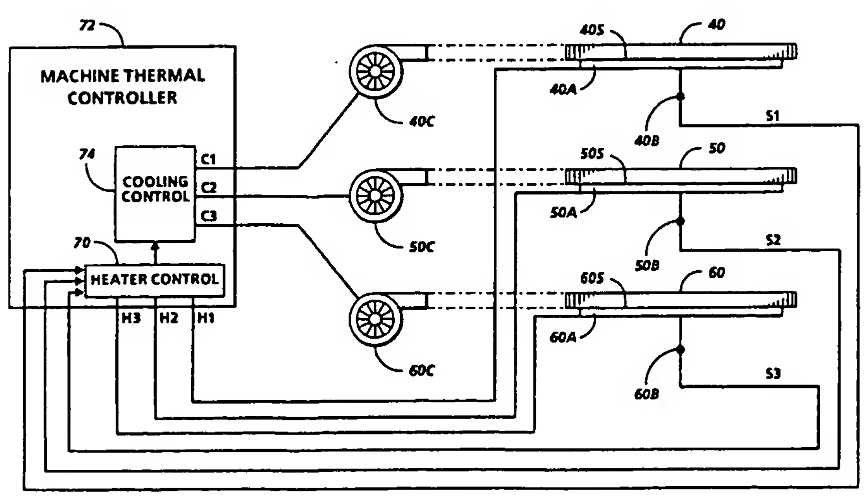

FIG. 2

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The present invention relates to printing systems incorporating light emitting print bars, and, more particularly, to a thermal control system for use with the print bars.

Image print bars used in xerographic recording systems are well known in the art. The print bar generally includes a linear array of a plurality of discrete light emitting sources on a substrate. The print bar is optically coupled to a linear lens array. Light emitting diode (LED) print bars are preferred for many recording applications. In order to achieve high resolution, a large number of light emitting diodes, or pixels, are arranged in a print bar and means are included for providing a relative movement between the print bar and the photoreceptor so as to produce a scanning movement of the print bar over the surface of the photoreceptor. Thus, the photoreceptor may be exposed to provide a desired image one line at a time as the LED print bar and associated lens array is advanced relative to the photoreceptor either continuously or in stepping motion. Each LED pixel in the print bar is used to expose a corresponding area on the photoreceptor to a value determined by image defining video data information.

In a color xerographic system, a plurality of LED print bars may be positioned adjacent the photoreceptor surface and selectively energized to create successive image exposures, one for each of the three basic colors. A fourth print bar may be added if black images are to be created as well.

Figure 1 shows a prior art single pass color configuration having three print bars, 10, 12, 14. The print bars, each comprising an LED array and a coupling gradient index lens array (10A, 10B, 12A, 12B, 14A, 14B, respectively), are addressed by video image signals whose application is controlled by control circuit 15. Each print bar is optically coupled to focus the emitter outputs to form three spaced latent images I_1, I_2, I_3 on the surface of photoreceptor belt 16. The optical coupling is accomplished by the gradient index lens arrays 10B, 12B, 14B, the lens array sold under the name $\text{SELFOC}_{\text{TM}}$ a trademark of Nippon Sheet Glass Co., Ltd. Upstream of each exposure station, a charge device 18, 20, 22 places a predetermined charge on the surface of belt 16. Downstream from each exposure station, a development system 26, 28, 30, develops a latent image of the last exposure without disturbing previously developed images. Further details of xerographic stations in a multiple exposure single pass system are disclosed in U.S. Patent 4,660,059.

With such a system as that disclosed in Figure 1, each colored image must be precisely aligned such that all corresponding pixels in the image areas are registered. The print bar alignment requirements are that pixels of each bar be aligned in the scan or Y-direction of Figure 1 so that each active write length is equal. The print bar must also be aligned in the skew or X-direction. This alignment must be maintained through continuous revolutions (passes) of the photoreceptor.

To maintain exact color registration of each image, typically to a tolerance of $\pm 0.1\mu$, the overall length of the write area, the pixel to pixel placement, and the straightness of the image line must all be within the required exacting tolerance. One of the most difficult manufacturing tolerances to achieve is the overall or active write length of an image print bar. For example, for a 14.33" LED print bar with 300 spi resolution, 4299 pixels are aligned in the active write area and a $\pm 15\mu$ tolerance in write length is typical.

A specific problem in correcting exact image-to-image registration is the change in length an LED print bar undergoes when subjected to temperature increases (thermal expansion), which are caused either by heat generated internally to the print bar, or by heat absorbed by the print bar from the surrounding machine environment.

Typically, accurate LED print bars are formed on a single ceramic substrate with a CET (coefficient of thermal expansion) on the order of 7.0×10^{-6} linear units /°C. To achieve proper registration (for a $\pm 10\mu$ tolerance due to thermal effects) of all pixels over a 364 mm write zone (B4 paper size), the temperature of all multiple print bars would have to be held to ± 3.9°C. An additional factor which must be considered is the need to compensate for the decrease in conversion efficiency of electrical to optical energy. For example, Ga AsP LED material illumination efficiency decreases approximately 0.8% per°C.

It is an object of the present invention to provide a thermal control system and method which enables multiple print bar temperatures to be maintained within specific required limits.

In accordance with the present invention, the temperature of each print bar is sensed and representative signals sent to a machine thermal controller to provide individual heating or cooling to maintain the print bar temperatures within a given tolerance as required for a dot-to-dot placement accuracy.

More particularly, the invention provides a thermal control system for maintaining the relative temperature of multiple print bars within a specified temperature differential range comprising:

a heater connected to each print bar and adapted, when energized, to increase the print bar temperature,

a temperature sensor associated with each print bar adapted to continually sense the operating temperature of the associated print bar and to generate an output signal representative thereof,

a cooling mechanism operatively coupled to each print bar to provide a cooling medium to one end of the print bar, and adapted, when energized, to decrease the temperature of the associated print bar,

system control means for selectively controlling the temperatures of each of the print bars, said temperatures represented by signals from the associated temperatures sensor, and for detecting a predetermined temperature differential between two or more print bars, said control means further adapted to control the operation of said heaters and cooling mechanisms to restore the sensed temperature differential to within the specified differential range.

In accordance with one aspect of the invention, said sensor output signals are sent to a heater control circuit within the system control means, said heater control circuit adapted to detect a temperature differential greater than said specified differential between two or more print bars and to enable a cooling control circuit within said system controller, said cooling control circuit adapted to provide cooling to the print bar having the higher detected temperature to restore the temperature differential to within the specified range.

In accordance with another aspect of the invention, said output signals are sent to control circuit within the system control means, said control circuit adapted to detect a temperature differential greater than said specified differential between two or more print bars and to enable a heater associated with the print bar having the lower detected temperature so as to increase the operating temperature of the heated print bar to restore the sensed temperature differential to within the specified range.

The present invention further provides a colour imaging recording apparatus for superimposing a plurality of images of different colors on one another to form a composite color image on a moving photoreceptor belt, said color image apparatus comprising a plurality of LED print bars arranged adjacent to the photoreceptor belt surface, each print bar adapted to create an exposure pattern along an active write length, corresponding with one of said plurality of color images, each said print bar having a plurality of LEDs which are selectively energized to form the latent image pattern, a plurality of gradient index lens arrays, each array associated with one of said print bars to transmit outputs of said print bars to form said exposure pattern, and means for compensating for temperature-induced variations in the active write length of each array, so as to maintain precise registration of said color images, said means comprising means for selectively heating or cooling one or more print bars, in response to detected temperature deviations, so as to maintain the print bars within a preselected temperature range, with respect to each other.

The following prior art has been noted:

US. Patent No. 4,865,123 to Kawashima et al. discloses an apparatus for circulating a cooling fluid through a plurality of cooling modules for cooling electronic components. The apparatus includes a plurality of supply lines arranged independently and in parallel to each other. Each of the supply lines supplies coolant to an individual cooling module. At one end, the supply lines draw coolant from a mixing tank having a relatively large volume, and at the opposite end, the supply lines return the coolant to the mixing tank, wherein the coolant is circulated so that its temperature is kept uniform throughout. Each supply line includes a pair of pumps 3, check valves 4, and a heat exchanger 5.

U. S. Patent No. 4,601,328 to Tasaka et al. discloses a method for temperature balancing control of a plurality of heat exchangers used in parallel. The temperatures of a medium flowing through the parallel heat exchangers are sensed at the same position in each of the plurality of heat exchangers, and the sensed temperature values are respectively compared with a temperature setting value, so as to calculate control signals for balancing the temperatures of the medium flowing out of the heat exchangers. Regulation means for each of the respective heat exchangers are responsive to the control signals to effect temperature balance of the medium.

By way of example only, an embodiment of the invention will be described with reference to the accompanying drawings, in which:

Figure 1 shows a top perspective view of a prior art multi-print bar imaging system.

Figure 2 shows a block diagram of the thermal control system, according to the present invention, that maintains multiple print bar temperatures within a specific required tolerance range.

Referring again to Figure 1, it is assumed that LED print bars 10, 12, 14 have a resolution of 300 spots per inch (300spi), and a pixel size of 50 x 50 microns on 84.67 micron centers. In an application, where an 8.5 inch wide informational line (active write length) is to be exposed, a linear LED print bar of approximately 2550 pixels, arrayed in a single row, would be required.

It is assumed that the print bars will be operated in an environment where temperature increases will be experienced that would change (increase) the active write length of one or more of the LED bars 10, 12, 14. For example, the print bars may be located within a xerographic machine frame which, because of other thermal loads, will experience an internal temperature rise (ΔT). The

actual rise will depend on the system and its specific operating parameters. Based on observations of present systems, an internal temperature rise of approximately 20 • C can be expected. In addition, room ambient temperature difference adds another 14 • C of ΔT to the temperature tolerance stackup. Print bar to print bar average operating power differences also add an additional complexity to the system.

Referring now to Figure 2, LED print bars 40, 50, and 60 are shown. These print bars are shown as representative. A fewer or greater number of print bars may be required, depending on the particular configuration. For example, for a full color system, four print bars, one for each of the primary colors and one for black, may be required. The charge and development system shown in Figure 1 would be modified accordingly. These print bars would be mounted, for example, in a printing system of the type shown in Figure 1. For ease of description, the xerographic stations and the coupling lens array shown in Figure 1 are omitted from this discussion, but it is understood that the print bars would be addressed and would expose the photoreceptor as is known in the art and as is shown in Figure 1. Of particular interest is how the print bars are modified so that their temperature can be controlled, in response to deviations in print bar to print bar temperatures. Each print bar has a resistive heating element (heater) 40A, 50A, 60A, connected respectively to the substrates 40S, 50S, 60S, of print bars 40, 50, 60, respectively. The heaters may extend along the length of the bar, as shown, or may assume other configurations consistent with usage.

The heater requirement is to raise an unused "cool" print bar close to the temperature of an active "hot" print bar. A heater power near the operating power of the "hot" print bar will generally be required. Each heater has an associated temperature sensor, 40B, 50B, 60B, which monitors the substrate temperature for each print bar and generates an appropriate signal, which represents the sensed temperature. The signal is sent to heater control circuit 70 in thermal controller 72. The sensors may be, for example, thermistors or junction devices.

Referring still to Figure 2, cooling mechanisms 40C, 50C, 60C are positioned so as to direct a cooling medium against the edge of each print bar 40, 50, 60, respectively. The cooling medium (in this case air) is directed through cooling ducts (not shown). With the forced air system shown, it is preferable that air be taken from outside the machine environments, so that the temperature rise of the air, due to internal heating, is minimized. Alternative cooling systems that may be used are liquid cooling systems or Peltier cooling devices.

In operation, the print heads, with usage, experience individual temperature changes. A predetermined temperature differential between the print bars has been stored in memory in controller 72. As an example, it is assumed that the print bars must operate with no more than a 3.9 • C temperature gradient differential between the bars. Machine thermal control circuit 70 receives signals from sensors 40B, 50B, 60B, and continually monitors the input from the print bars during operation and compares the several temperatures with each other. Upon noting a deviation of more than 3.9 • C between at least two of the bars, either one or more cooling mechanisms or heaters are selectively activated. In a preferred embodiment, the cooling control system 74 is enabled to first attempt to cool the print bar which is identified as having the hotter relative temperature. For example, if print bar 40 temperature is sensed along line S1 at 36 • C, and print bar 50 along line S2 at 34 • C, and print bar 60 along line S3 at 30 • C, comparison circuitry in heater control circuit 70 recognizes that print bars 40 and 60 have a temperature differential greater than 3.9 • C. A signal is sent to cooling control circuit 74 to generate a signal to energize cooling mechanism 40C along line C1. Upon detecting a drop in print bar 40 temperature to 35 • C (in heater control circuit 70), cooling mechanism 40C will be de-energized. If the print bar 40 does not respond quickly enough to the cooling, as detected by a timing mechanism initiated in controller 72 at the time of cooler mechanism 40C activation, the cooling mechanism 60C will be disabled, the control circuit 70 enabled, and heater 60A will be energized, raising the temperature of print bar 60. The heater power of heater 60A will cause the temperature of bar 60 to elevate, reducing the temperature differential between bar 40 and bar 60 to less than 3.9 • C. In practice, a combination of heating and cooling may be used e.g. for the example given, print bar 40 may be cooled and print bar 60 may be heated to rapidly reduce the temperature differential between the two. The control circuit will be set to maintain as low an average absolute print bar temperature as possible, to optimize LED efficiency, while maintaining the temperature of each of the print bars within the necessary maximum differential temperature.

While the above description includes a specific example of a preselected temperature differential, it is understood that other differential ranges may be provided and other possibilities exist for maintaining differentials between two other print bars, or between all three print bars requiring cooling or heating combinations to provide both heating and cooling.

Other modifications of the control system are possible. As one example, the heater shown in Figure 2 may be modified so that areas adjacent the input cooling duct have a higher power density to compensate for the cooler air directed against that end and to compensate for conductive heat losses through the print bar mounts.

Claims

1. An imaging, system comprising a plurality of light-emitting print bars (40,50,60) which are selectively energizable to expose a light sensitive surface, and a thermal control system comprising means for selectively changing the operating temperature of one or more print bars, in response to detected temperature deviations, so as to maintain the operating temperatures of the print bars within a preselected differential range, with respect to each other.

2. An imaging system as claimed in claim 1, wherein the thermal control system comprises:
   a respective heater (40A,50A,60A) for each print bar, the heater being adapted, when energized, to increase the print bar temperature,
   a respective temperature sensor (40B,50B,60B) associated with each print bar, the sensor being adapted to continually sense the operating temperature of the associated print bar and to generate an output signal representative thereof,
   a respective cooling mechanism (40C,50C,60C) for each print bar, the cooking mechanism being adapted, when energized, to decrease the temperature of the associated print bar, and
   system control means (72) for selectively controlling the temperature of each of the print bars by detecting the temperature differential between two or more print bars, and thereafter selectively energizing the heaters and cooling mechanisms to restore the detected temperature differential to within the preselected range.

3. An imaging system as claimed in claim 2, wherein said system control means includes means for storing data associated with a predetermined maximum temperature differential between said print bars, said control means further including heater control means controlling said heaters and cooling mechanisms by receiving said output signals from said temperature sensors and comparing each of the print bar temperatures with said maximum temperature differential between said print bars and, when detecting a temperature differential that exceeds said predetermined maximum temperature differential between said print bars, selectively energizing said heaters and said cooling mechanisms to restore said detected temperature differential to within said predetermined maximum temperature differential.

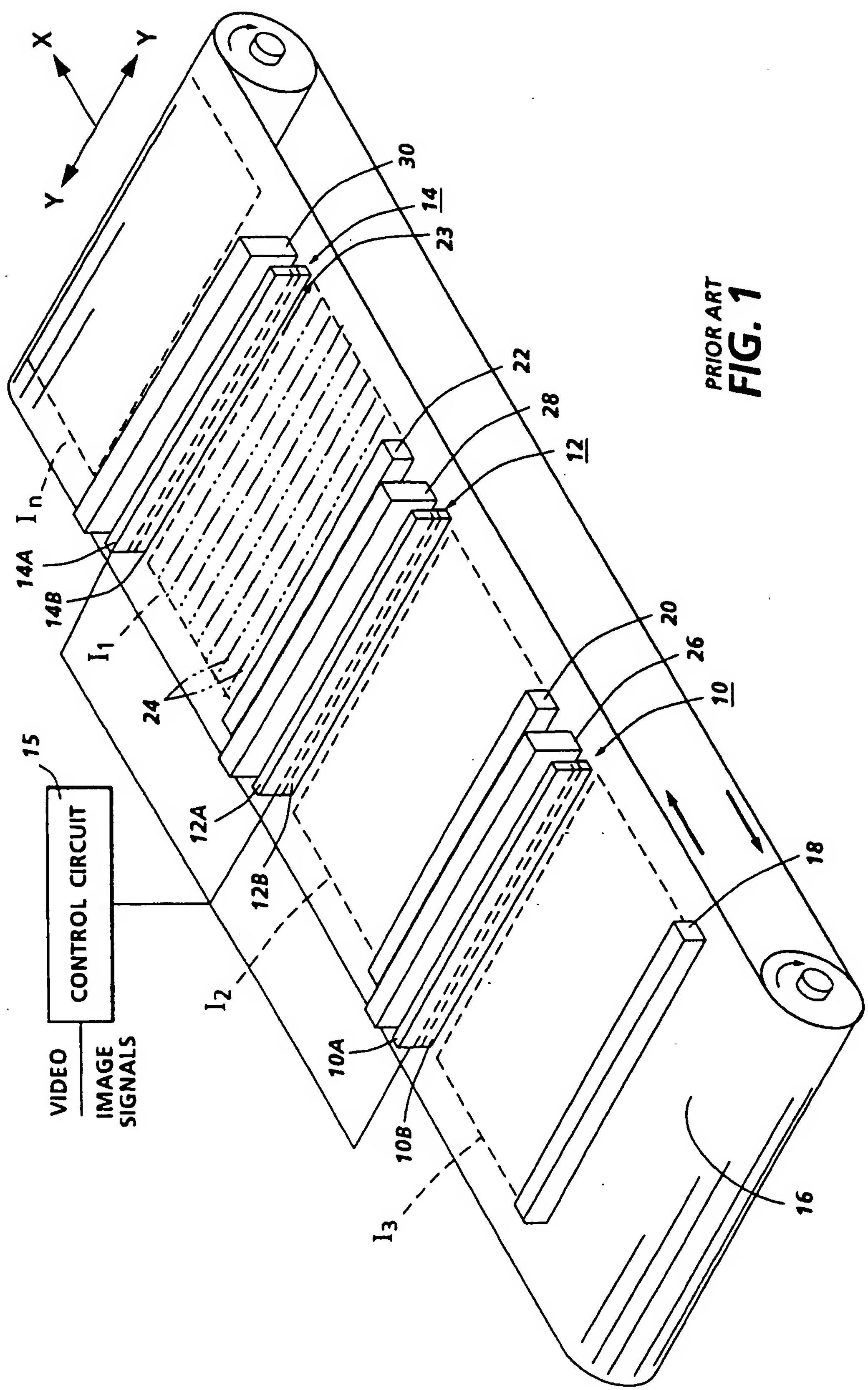
4. An imaging system as claimed in claim 3, wherein the heater control means is operable, when a temperature differential that exceeds the predetermined maximum temperature is detected, to energize the heater associated with the print bar having the lower temperature and/or to energize the cooling mechanism associated with the print bar having the higher temperature.

5. An imaging system as claimed in any one of claims 2 to 4, wherein each print bar is formed on a respective substrate (40S,50S,60S) to which the respective heater is connected.

6. An imaging system as claimed in claim 5, wherein the respective cooling mechanism presents a cooling medium to one end of the substrate and the heater has a power density gradient which provides greater heat to that end of the substrate.

7. An imaging system as claimed in any one of the preceding claims for superimposing a plurality of images of different colors on one another to form a composite color image on the light sensitive surface, wherein:
   each print bar is adapted to create an exposure pattern along an active write length, corresponding with one of said plurality of color images, each said print bar having a plurality of LEDs which are selectively energized to form the exposure pattern, and wherein
   a respective gradient index lens arrays (10B,12B,14B) is associated with each print bar to transmit the output of said print bars to form said exposure pattern.

8. A method for controlling overall length of LED print bars by maintaining the print bars within a preselected temperature range with respect to each other, the method including the steps of:
   sensing the operating temperature of each print bar and generating signals indicative thereof,
   detecting whether two or more print bars are operating at temperature differentials greater than a predetermined differential range, and
   adjusting the temperature of one or more print bars to restore the temperature differential to within the predetermined range.



PRIOR ART
FIG. 1

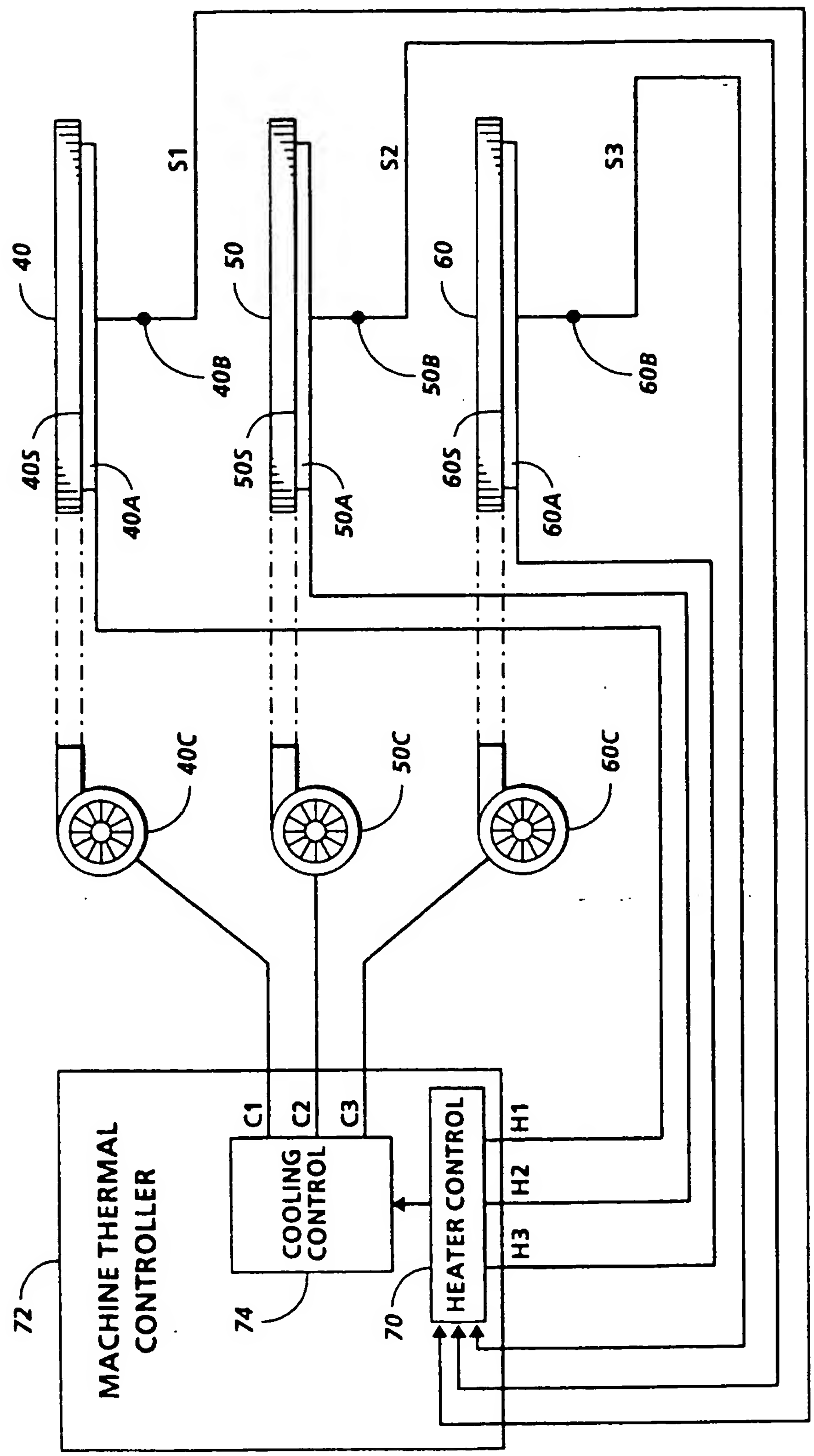

40
50
60
S1
S2
S3
40B
50B
60B
40S
50S
60S
40A
50A
60A
40C
50C
60C
MACHINE THERMAL CONTROLLER
72
C1
C2
C3
COOLING CONTROL
74
HEATER CONTROL
70
H1
H2
H3

FIG. 2

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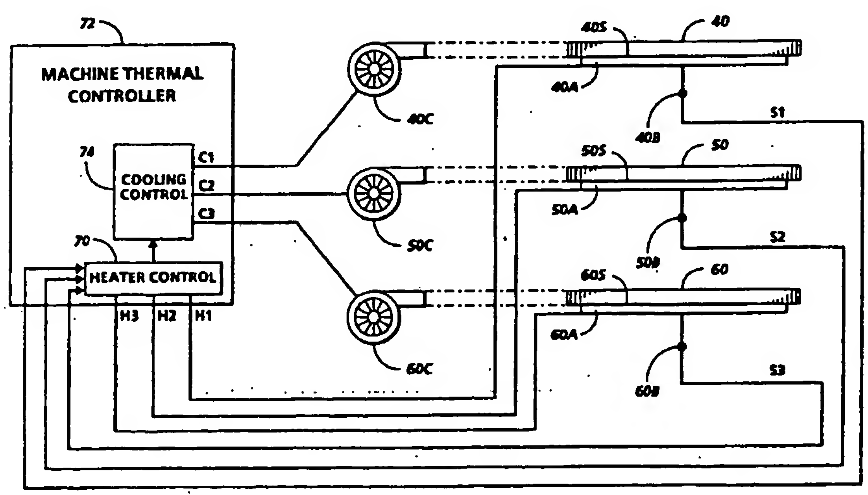

FIG. 2

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92311379.9

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	DE - A - 4 003 118 (MONARCH) * Fig. 1; abstract; claims *	1	G 03 G 15/00 G 03 G 15/01
A	* Fig. 1; abstract; claims *	2-4	
X	EP - A - 0 276 978 (MATSUSHITA) * Fig.; abstract; claims *	1	
A	* Fig.; abstract; claims *	2-5,8	
D,Y	US - A - 4 865 123 (KAWASHIMA) * Fig. 1-3; abstract; claim 1 *	1,2	
D,A	* Fig. 1-3; abstract; claim 1 *	3,4,8	
P,Y	EP - A - 0 516 247 (SHINKO ELECTRIC) * Fig.; abstract *	1,2	
P,A	* Fig.; abstract *	3,4,8	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	US - A - 4 589 057 (SHORT) * Fig.; abstract; claims *	1-3,5,6	G 03 G 15/00 B 41 J 2/00 B 41 J 3/00 H 01 L 23/00 H 05 K 7/00 B 41 J 29/00 G 01 D 9/00
A	EP - A - 0 155 975 (HONEYWELL) * Fig. 1,2; abstract; claim 2 *	1-3	
A	US - A - 4 896 168 (NEWMAN) * Fig.; column 4, line 58 - column 5, line 17 *	1,2	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	30-12-1993	KRAL

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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